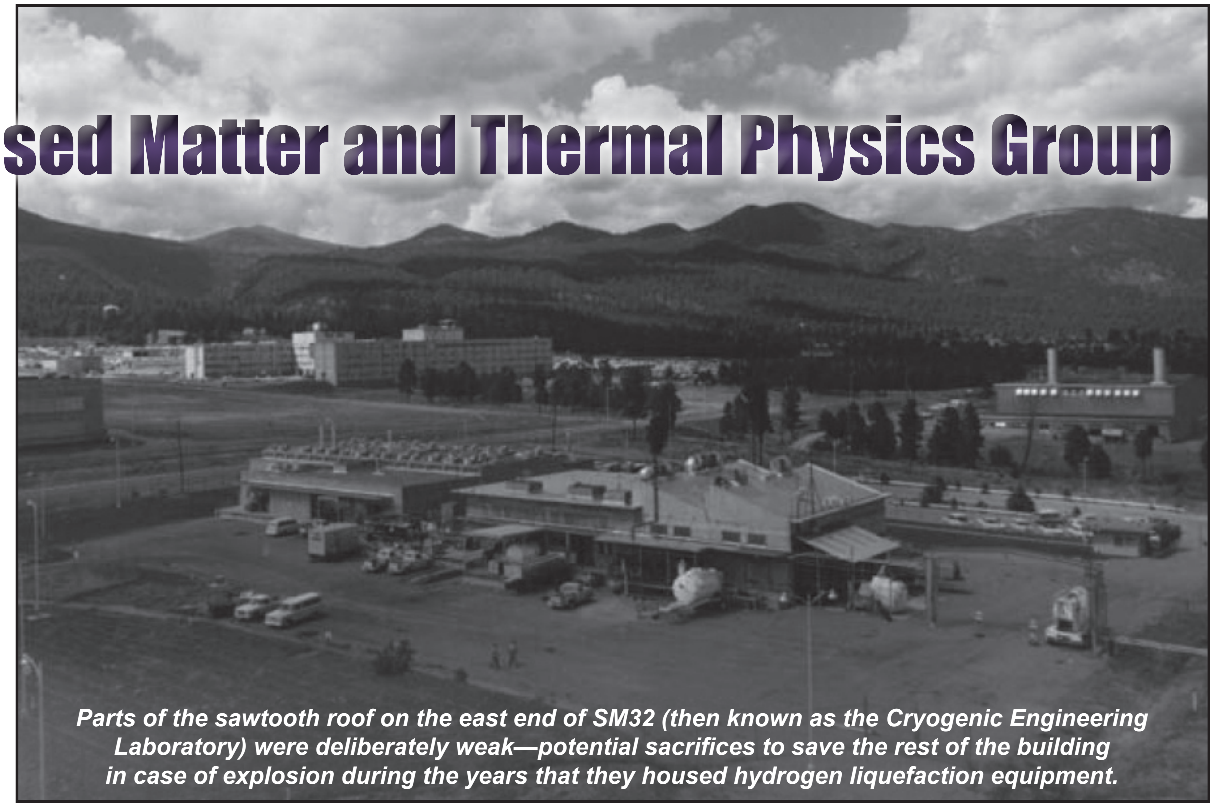
LALP-07-094 Winter 2008

Condensed Matter and Thermal Physics Group



The facilities that house most of the group as they appeared in 1957 when the only other nearby buildings were the Chemistry, Metallurgy Research Building (left), the Administration building (background), and the steam plant (right background).

Parts of the sawtooth roof on the east end of SM32 (then known as the Cryogenic Engineering Laboratory) were deliberately weak—potential sacrifices to save the rest of the building in case of explosion during the years that they housed hydrogen liquefaction equipment.

The group known today as Condensed Matter and Thermal Physics at Los Alamos National Laboratory has a history almost as long as that of Los Alamos itself. Originating in the Chemistry, Metallurgy Research (CMR) Division and now part of Materials Physics and Applications (MPA), the group focuses on experimental condensed-matter science at cryogenic temperatures, with thermodynamics its primary theme and low-temperature physics and cryogenic engineering additionally.

Photo courtesy of National Nuclear Security Administration/Nevada Site Office.

Mike, the first large-scale experiment with thermonuclear fusion, 1952.

Plutonium arrives, investigations begin

With the first shipments of milligram quantities of plutonium to Los Alamos in 1943 a thrilling pace of physical-chemistry and metallurgical investigations of plutonium and its alloys ensued, driven simultaneously by the unbelievable excitement of learning about a completely new element and the urgent need to deliver the "pit" for Trinity, the first nuclear explosion.

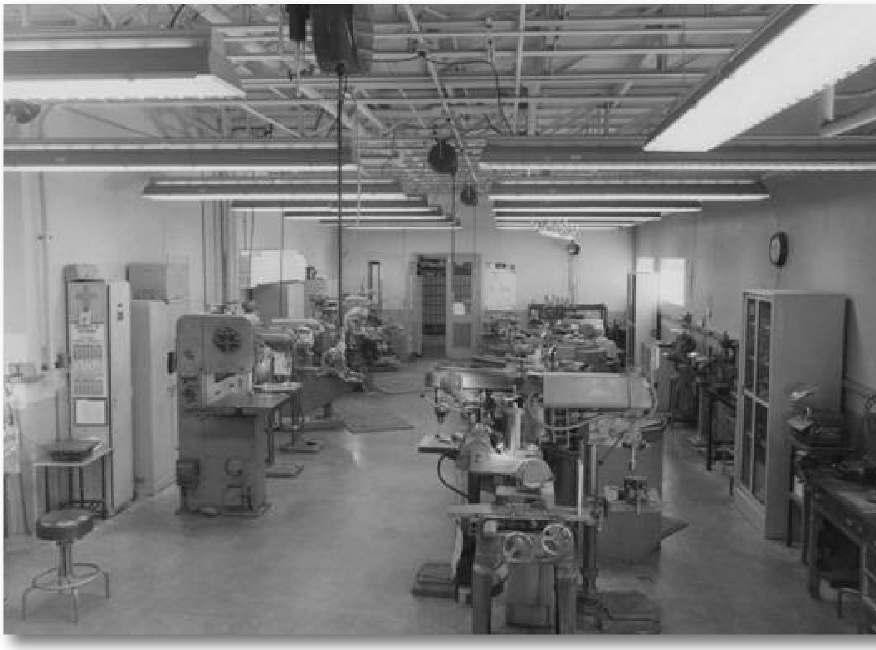
After the end of World War II opportunities for fundamental science arose hand in hand with the ongoing development of nuclear weapons. The earliest group members initially teamed to determine the properties of plutonium with high precision, recognizing that measurements of some of its properties at cryogenic temperatures were essential in understanding this unusual metal and for accessing the practical issue of the thermal stability of properties below room temperature. These early studies included isothermal compressibility, sound velocity, and thermal conductivity measurements that later were extended to electrical resistivity and specific heat, thus leading to the Metals Physics group in 1945.

Low temperature physics studies

The group's cutting-edge fundamental science and practical support of the mission of Los Alamos Scientific Laboratory expanded in the late 1940s with a new applied focus: the so-called "Super," using a fission trigger to unleash the energy of fusion of light nuclei. It was known that deuterons fuse much more easily than protons and that a high initial density of deuterons was advantageous, so it was obvious that research on the fundamental properties of cryogenic liquid deuterium would be needed, as well as engineering research into the separation and purification of the hydrogen isotopes and the liquefaction, storage, and transport of deuterium. Tritium—the radioactive isotope of hydrogen—was also of interest. In 1948, the group was renamed Low Temperature Physics and Cryoengineering, and undertook a systematic scientific and engineering study of the low-temperature thermodynamic and transport properties of all the helium and hydrogen isotopes. This fundamental work was punctuated by the "Mike" shot at Eniwetok Atoll, using liquid deuterium fuel and producing a thermonuclear yield of roughly 10 megatons of TNT.

Many group members of that era somehow accomplished both fundamental research and meaningful participation in Mike and other South Pacific weapons tests. When the group's new building was opened in the mid 1950s, the street in front was named

Eniwetok in memory of those intense years of work. Although cryogenic liquid deuterium was soon replaced by room-temperature solid lithium deuteride as the fuel for thermonuclear weapons, the extensive low-temperature science and engineering associated with Mike underpinned other important future developments ranging from the use of liquid hydrogen as space-shuttle fuel through the development of standards for safe handling of large quantities of cryogenic liquids to the physics of superfluid helium.



The group's machine shop has changed little through many decades, until the present era of numerically controlled machines. Under microscopic examination, the calendar on the left in this photo displays January 1964 and the floor in the foreground is littered with doughnut crumbs—evidence that the group's traditional celebration of the exceptional work done by the technicians goes back at least 43 years.

To appreciate the scientific excitement of low-temperature physics in this era, remember that helium superfluidity was not discovered until 1937 and the two-fluid model of superfluidity was not established until the late 1940s. As with plutonium earlier, with ^{3}He the group took advantage of the unique opportunity to explore the properties of an entirely new material, motivated and enabled by applied work. The natural abundance of ^{3}He is tiny, but thermonuclear weapons production established a new, industrial-scale production of tritium, which decays with a 12-year half-life into ^{3}He, giving the group the first access to this fascinating and complex solid and liquid. The group accomplished the historic initial liquefaction of ^{3}He in 1948 and performed measurements of its thermodynamic and transport properties throughout the 1950s.

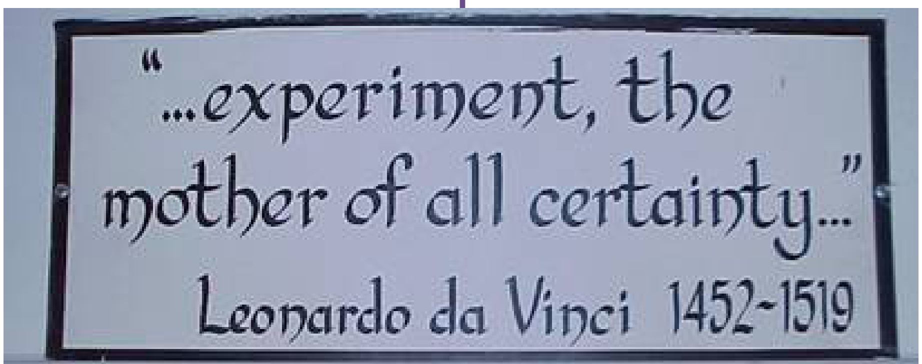
Remember, too, that this was an era when most research equipment was still built by technicians—not bought from companies—and experiments were still done by people —not by computers. Each cryostat and its associated plumbing were individually designed and carefully built. Data acquisition rates and accuracy were usually limited by how well group members could read mercury manometers, analog galvanometers, and optical levers with linear scales, and how quickly and accurately they could write the numbers in lab books. Temperatures were held constant by homemade rubber-membrane manostats regulating the pressure in pumped helium baths, or in rare, sophisticated circumstances by homemade electronic feedback circuits using vacuum tubes. Data analysis relied mostly on pencils, paper, and slide rules. (Later, a lab book might occasionally be taken to the administrative staff whose job it was to transcribe data onto IBM punch cards for processing at the central computing facility.) Secretarial skill was measured by the number of typing errors per page of technical manuscript, a number that was often far smaller than one, despite staff member handwriting that made the distinctions between words like "monatomic" and "monotonic" a matter of judgment for the typist.

By the mid 1960s, the "Low Temperature Group" exhibited a tremendous breadth of interests in low-temperature physics. Scientific studies underway included equation of state and thermal properties of the helium isotopes, neutron diffraction studies of solidified gases, superfluid hydrodynamics, superconductivity, Mossbauer studies of lattice dynamics and magnetism, the Kondo effect, and nuclear physics with cryogenic polarized targets. Cryogenic engineering research and development in that era included measurement of transport properties of helium and hydrogen liquids, the design and construction of several superconducting magnets and radio-frequency cavities for use elsewhere at Los Alamos, and solid hydrogen and deuterium target development for the Los Alamos Meson Physics Facility. At the interface between low-temperature physics and cryogenic engineering, the group had the first working ^{3}He-^{4}He dilution refrigerator in the country, thanks to the technician who assembled it perfectly leak-free on his first attempt; and one of the group's early dilution refrigerators stayed cold for three months—a remarkable accomplishment at the time.

Embargo triggers energy research

In the 1970s, a new national need gained attention, and the group responded again with a combination of fundamental research and technology development. The 1973 OPEC oil embargo triggered the widespread realization that US energy sources were being depleted and imported energy was undependable; furthermore, acid rain and other pollution were problematic. Many group members naturally carried their low-temperature-physics and cryogenic-engineering talents into energy research and development. Fundamental work included research on flux motion, losses, and pinning in Type II superconductors, dielectric breakdown at cryogenic temperatures, properties of A15 superconductors (e.g., Nb^3Ge), and the stability of superconductor/normal-metal composites, while applied efforts included the development of dc and ac superconducting power transmission lines, superconducting magnetic energy storage for electric utilities, a car fueled by cryogenic hydrogen, and cryogenic distilla-

This sign has been hanging above the front door of our building for as long as we can remember. (Note: da Vinci was not a member of our group.)



Summarizing the activities of hundreds of people over the course of 60 years in such a short note is a matter of brutal down-selection. Many precious memories are unrecorded here; entire lines of research whose stories could each occupy many pages have been completely omitted.

Nevertheless, we hope this short note communicates the pride that we feel for the history of our group, for its responsiveness to the applied needs and the scientific frontiers in each decade of its existence, and for its enduring commitment to technical excellence.

Greg Swift and Joe Thompson, 2006
(We gratefully acknowledge documents and stories from Ed Hammel, Dean Taylor, Jim Hoffer, and Marty Maley.)

tion purification of hydrogen isotopes for fusion-energy fuel. Federal support for such energy R&D dropped abruptly in the early 1980s, but many of these developments are receiving renewed attention today, and significant spin-offs from that era of the group, such as the Los Alamos Tritium Systems Test Assembly, now have significant histories of their own.

In the late 1970s and early 1980s, the study of thermodynamic cycles and processes, and the relevant properties of materials used in them, began with an effort in magnetic refrigeration and later included engines and refrigerators using liquids near their critical points. Advances in magnetic refrigeration quickly took that team out of the group and into industry. ^{3}He–^{4}He mixtures below 1 Kelvin proved to be ideal for studying the fundamentals of yet another type of thermodynamic process: spinodal decomposition of supersaturated phase transitions. Another aspect of our group's focus on cycles and processes, the development of the fundamentals and applications of thermoacoustic engines, refrigerators, and (later) mixture separators, began in 1981 with the invention of the thermoacoustic refrigerator in the group. In the 1990s, the thermodynamic-cycles and -processes focus grew further to include the invention and development of tiny hollow, spherical, cryogenic deuterium-tritium shells for inertial-confinement fusion targets, an effort which soon matured and moved out of the group.

Condensed matter and thermal physics focus

The early to middle 1980s was a transitional period for fundamental research in the group, refocusing on more fundamental problems in fluid dynamics and on strongly correlated f-electron phenomena. Appropriate to this change in fundamental focus and to the continuation of thermodynamic-cycle and -process research, the group's name was changed to Condensed Matter and Thermal Physics. Correlated-electron phenomena, fundamentals of fluid dynamics, and thermoacoustics remain central research themes of the group.

The fluid-dynamics focus of the 1980s included an experimental program in chaos, pattern formation, and turbulence, which continues today. Still based in part on low-temperature techniques, the fluids focus also served as an incubator for a cryogenic neutrino-mass experiment based on spin-polarized hydrogen in the 1980s. In the 1990s, the fluids focus expanded to include the study of lead-bismuth mixtures and other liquids, and their interactions with steels, of interest in advanced nuclear reactors and the accelerator transmutation of nuclear waste; and the thermoacoustics team began the development of thermoacoustics for industrial-scale liquefaction of natural gas.

The research focus on correlated-electron materials, their growth as single crystals, and earlier experience with applications of superconductors positioned the group to respond immediately to the 1986 discovery of high-temperature superconductivity. As in many other laboratories around the world, this discovery marked a sea change in the group and triggered the expansion of experimental capabilities necessary to explore and understand this surprising phenomenon. By the end of the 1980s, these capabilities included electronic transport, thermodynamics, heat transport, and nuclear-magnetic and muon-spin resonance. Los Alamos, like the rest of the nation, saw high-temperature superconductivity as an opportunity to reinvigorate energy-related research, and formed the Superconducting Technology Center from a nucleus of group members to develop applications of this discovery.

Fundamental research on strongly correlated electron physics, including f-electron and cuprate materials, remained in the group and provided a basis for Los Alamos to collaborate with the state of Florida in establishing the new National High Magnetic Field Laboratory. With the group's interests in the physics of correlated materials at extremes of low temperatures and high pressures, it was natural for the newly created Los Alamos Pulsed Field Facility to find its home in the group until 1998, when the magnet lab spun off as a separate Laboratory center.

Diversification

During the 1990s, the group also diversified into ultra-fast optics (which opened new windows for investigating correlated-electron materials but also impacted weapons diagnostics), started an effort in magnetic resonance force microscopy, and added neutron scattering and photoemission to its growing repertoire of materials-characterization techniques.

These years laid the foundation for the 2002 discovery in the group of the first plutonium-based superconductor, a direct result of the group's earlier work on related heavy-fermion superconductors and magnets.

With this discovery and with photoemission research, part of the group returned to its roots in the study of plutonium.

Despite its continuing relevance to the Los Alamos's mission, relatively little progress had been made on fundamental understanding of the "plutonium problem" during the previous six decades, but superconductivity in the new plutonium compound opened entirely new avenues for investigation and engaged the international condensed-matter community in plutonium for the first time.

The Condensed Matter and Thermal Physics Group emphasizes fundamental research on condensed matter with complementary thrusts in thermal physics, correlated electron materials, actinide chemistry, and low-energy spectroscopy.

Thermal physics

MPA-10's thermal physics research and development activities have common roots in thermodynamics, fluid dynamics, and statistical mechanics. Projects range from fundamental research to industrial applications.

Team leaders

Thermoacoustics: Greg Swift, *swift@lanl.gov*
Nonlinear dynamics: Michael K. Rivera, *mkrivera@lanl.gov*
Advanced Fuel Cycle Initiative research and development: Ning Li, *ningli@lanl.gov*

Correlated electron materials

Materials physics research in MPA-10 is organized around "new physics through new materials," with an historical and continuing focus on discovering new phenomena in strongly correlated electron materials. The group's emphasis is on heavy-fermion systems where electronic correlations enhance the effective mass of charge carriers to as much as 1,000 times the mass of a free electron, leading to novel superconducting and magnetic behavior. MPA-10 also has a strong scientific and applied interest in novel plutonium and actinide materials.

Team leaders

Materials synthesis and characterization: Eric Bauer, *edbauer@lanl.gov*
Transport and thermodynamics: Filip Ronning, *fronning@lanl.gov*
New physics from novel materials at extreme conditions: Joe D. Thompson, *jdt@lanl.gov*
Very low temperature physics and magnetic resonance force microscopy: Roman Movshovich, *roman@lanl.gov*
Condensed matter nuclear magnetic resonance: Michael Hundley, *hundley@lanl.gov*
Photoelectron spectroscopy: John J. Joyce, *jjoyce@lanl.gov*
Mössbauer spectroscopy for solid-state Research: R. Dean Taylor, *taylor_r_dean@lanl.gov*
Neutron scattering: Wei Bao, *wbao@lanl.gov*

Actinide chemistry

The actinide chemistry effort in MPA-10 is a multidisciplinary research program that applies inorganic/organometallic 4f/5f-element, materials, fluorocarbon, organic, and metal-mediated catalytic and stoichiometric chemistry towards the nation's programmatic needs in defense, threat reduction, and energy. The team maintains collaborations across the Laboratory and is composed of the following interconnected research areas: actinide-ligand multiple bonds, 5f-electron delocalization and communication, transformations uniquely enabled by 5f-orbitals, actinide molecular magnetic materials, lanthanide-ligand multiple bonds, and transition metal, lanthanide and actinide fluorinated materials chemistry.

Team leader

Heavy element chemistry: Jaqueline L. Kiplinger, *kiplinger@lanl.gov*

Contact

Michael Hundley
MPA-10 Group Leader
Mail Stop K764
Los Alamos
National Laboratory
Los Alamos, NM 87545

Tel: 505.667.4129
Fax: 505.665.7652
e-mail: hundley@lanl.gov